AD-A264 982

REPORT DOCUMENTATION PAGE

2. REPORT DATE

March 1993

Professional Paper

4. TITLE AND SUBTITLE

ELECTROMAGNETIC WAVE PROPAGATION ASSESSMENT

PR: SXB3
PE: 0602435N
WU: DN888715

6. AUTHOR(S)

J. H. Richter

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
Block Programs
San Diego, CA 92152–5001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The roots of electromagnetic propagation research and development in AGARD go back to 1956 when the Ionospheric Research Committee was formed. In 1970, the present Electromagnetic Wave Propagation Panel was established covering the entire spectrum from very low radio through optical and higher frequencies. The effort under AGARD sponsorship during the past 35 years has resulted in an impressive amount of published literature in the form of conference proceedings, lecture series notes and working group reports. An example of a recent effort is an AGARDograph (No. 326) documenting the findings of a working group which addressed "Radio Wave Propagation Modeling, Prediction and Assessment." Much of the following presentation is based on material contained in the AGARDograph.

Published in *AGARD Highlights*, 92/1 March 1992, pp 6–14.

14. SUBJECT TERMS

electromagnetic
propagation
electro-optics
atmosphere

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

Electromagnetic Wave Propagation Assessment

by

Juergen H. Richter

It is customary for each Technical Panel in turn to make a presentation of aspects of its work to The National Delegates Board Meeting. At the meeting in Fall 1991 it was the turn of the Electromagnetic Wave Propagation Panel. Dr Richter, Deputy Chairman of the Panel, made the presentation. An edited version of his speech follows.

Introduction

Mr. Chairman, National Delegates, Ladies and Gentlemen: it is an honor and a pleasure to present to you some work conducted by members of the Electromagnetic Wave Propagation Panel (EPP). Since you have heard overviews of EPP's effort in the recent past, I will show you today a few examples of how important propagation assessment can be for military operations. I also will discuss areas of future direction for EPP.

The roots of electromagnetic propagation research and development in AGARD go back to 1956 when the Ionospheric Research Committee was formed. In 1970, the present Electromagnetic Wave Propagation Panel was established covering the entire spectrum from very low radio through optical and higher frequencies. The effort under AGARD sponsorship during the past 35 years has resulted in an impressive amount of published literature in the form of conference proceedings, lecture series notes and working group reports. An example of a recent effort is an AGARDograph (No. 326) documenting the findings of a working group which addressed "Radio Wave Propagation Modeling, Prediction and Assessment." Much of the following presentation is based on material contained in the AGARDograph.

Radio Wave Propagation Modeling, Prediction and Assessment

Military operations depend on communications, surveillance, navigation and electronic warfare systems which rely on propagation of electromagnetic waves in the earth's environment. Assessment and prediction of the performance of such systems are critical for their optimum use. This is illustrated for radiowave propagation in the lower atmosphere where, especially over the ocean, refractive layers may cause anomalous propagation conditions. Figure 1 shows how such a so-called surface-based duct may alter the radar coverage for a shipboard radar. The radar signals may propagate far beyond the normal horizon and permit extended coverage. At the same time, signals may be intercepted at unexpectedly large ranges. Above the layer trapping the electromagnetic energy, there may be a "hole" in radar coverage which can be exploited by an intruding aircraft or missile. In the case of a height-finder radar for which altitude is derived from the elevation angle of a narrow-beam radar, significant altitude errors may be encountered. Figure 2 shows the dramatic effect of such a surface-based duct on jamming operations and illustrates how knowing the environment can be used to military advantage. Figure 2 consists of two photographs of a shipboard radar display during operations off the southern California coast. The fact that the radar senses the coast line and several islands beyond its "normal" radar horizon indicates the presence of a ground-based duct. The left radar display was taken when a jamming aircraft flew high above the duct but only 26 nmi away. The radar is jammed over a very narrow angle along the radial to the jammer. The right radar display shows the jamming aircraft at more than twice the distance away from the ship but now at a low altitude of only 500 ft which is within the duct. Under standard atmospheric conditions, the ship's radar should not be affected by the jammer since it is far beyond the horizon. However, as one can see from the right side of figure 2, the duct channels the jamming energy very efficiently and the ship's radar is jammed over a wide range of angles (i.e., through radar sidelobes).

The scientific understanding and the ability to model anomalous propagation effects must be made available to the operational military community in a manner that can be readily used. This has been accomplished with the increased availability of computers and display technology. An early example of a stand-alone propagation assessment system for shipboard use is the Integrated Refractive Effects Prediction System (IREPS). This system provides radio and radar propagation assessment in a marine environment. Several tactical decision aids (TDAs) were developed. An example of a TDA is shown in

Surface-based Duct From Elevated Trapping Layer

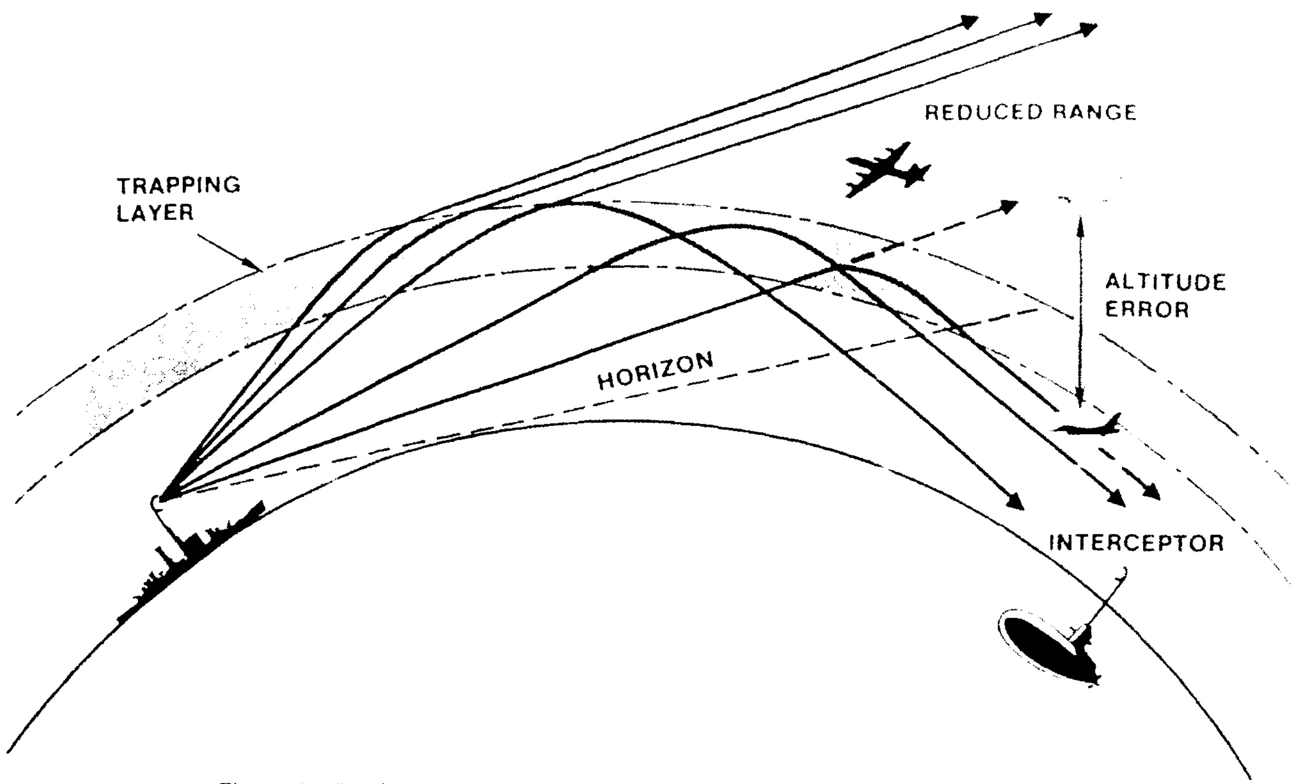

Figure 1. Radio propagation effects caused by atmospheric refractive layers

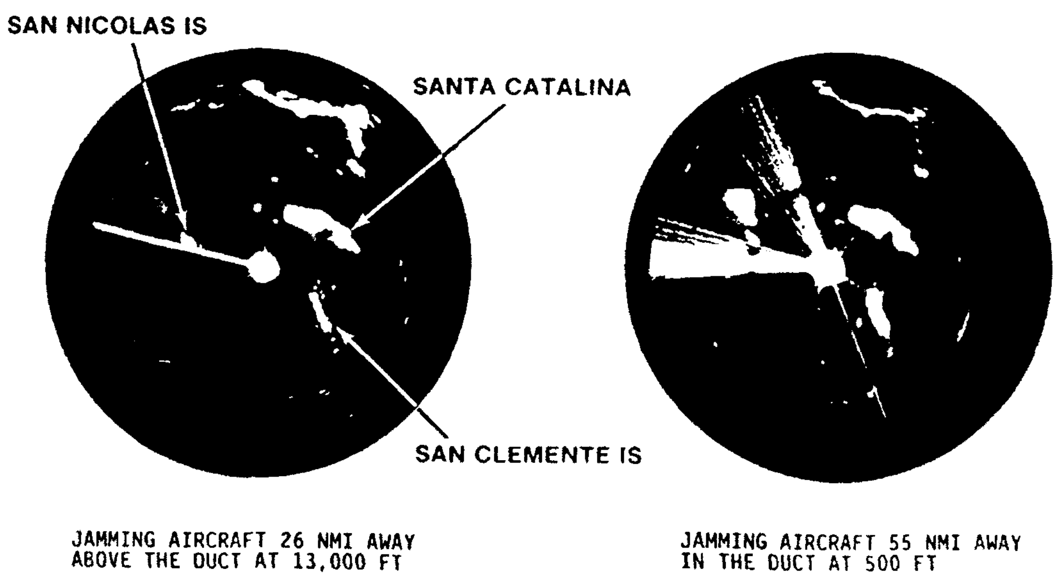

Figure 2. Jamming effectiveness under atmospheric ducting conditions (540 ft surface-based duct)

figure 3 for determining attack aircraft flight altitudes. The left side of figure 3 schematically displays a radar detection envelope under standard atmospheric conditions. An attack aircraft would avoid detection by flying low. The right side of figure 3 shows the radar detection envelope for ground-based ducting conditions when radar coverage may be greatly extended. Since a low flying aircraft would be detected at long ranges, a flight altitude just above the duct would best facilitate penetration without

detection. This TDA and others have become an integral part of military operations and demonstrate the success of translating the effect of complex geophysical conditions into military doctrine.

Another propagation assessment system became widely used for the assessment of high-frequency (hf) propagation and is called PROPHET. Long-range propagation for the hf frequency band (2—40 MHz) is determined by the structure of the ionosphere which is influenced by solar radiation. Prediction of hf propagation conditions requires a complex mix of analytical and empirical models. An example of a PROPHET product is shown in figure 4. Signal-strength contours are plotted for a 24-hour time period as a function of frequency. This display is for a specific propagation path (Honolulu to San Diego) and depends on solar radiation and ambient electromagnetic noise. The communications operator can determine from this display which frequency to use to suit specific communications requirements (MUF is maximum usable frequency, FOT is frequency for optimum transmission, LUF is lowest usable frequency). The hf-frequency spectrum will remain of importance to the military community in spite of advances in satellite communications for two reasons. First, it remains a back-up in case of satellite communications denial and, second, many countries (let alone terrorists and drug-traffickers) do not have satellite resources and rely on hf. HFDF (high-frequency direction finding) is, therefore, another important and very successful application of PROPHET and its many derivatives devoted specifically to this purpose.

While IREPS and PROPHET were developed as stand-alone systems, the complexity of modern warfare necessitated their incorporation into command and control systems. The high-level military decision maker must have real-time access to accurate environmental data which includes the propagation environment. An example is Tactical Environmental Support System (TESS) developed by the United States Navy which provides meteorological and oceanographic data to command and control systems (figure 5). TESS accepts forecast models from central sites, receives real-time meteorological and oceanographic satellite data and uses locally generated models and observations. TESS can either provide electromagnetic propagation data and TDAs directly or transfer properly formatted environmental input data to the respective components of command and control systems. Similarly, hf propagation assessment has been incorporated into frequency management systems.

Future Directions

Tropospheric Radio Propagation

In the area of tropospheric radio propagation modeling, the assumption made so far is that the atmosphere is horizontally stratified. This assumption is based on a physical reason since the atmosphere, in particular over ocean areas, is horizontally much less variable than vertically. Horizontal stratification also implies temporal persistence. Propagation forecasts are often based on persistence, i.e., it is assumed that present conditions will not change significantly in the near future. There are, however, conditions for which horizontal inhomogeneity may be important, for example at air mass boundaries, in coastal regions or over complex terrain.

While mathematical techniques to model propagation in horizontally varying environments have existed, they were cumbersome and not suited for real-time assessment. Fortunately, a technique called the parabolic equation approximation has been adapted to tropospheric radio propagation during the past decade and, in combination with other techniques, appears to be the solution for fast computation of signal coverage in horizontally varying propagation environments. Figure 6 is an example of a radar coverage diagram for which a surface-based duct rises linearly from the surface at range zero to an altitude of 300 m at a range of 100 km and then decreases to the surface at a range of 200 km. The coverage diagram is based on a hybrid model which uses the parabolic equation approximation at low altitudes and ray-optics techniques at higher altitudes (Hitney, AGARD CP 502, pages 1.1—1.5, to be published in Spring 1992). Future work will include surface roughness effects and propagation over terrain.

The major problem of operational assessment of propagation in inhomogeneous refractivity conditions is not the propagation modeling part but the timely availability of the temporal and spatial structure of the refractivity field. There are presently no sensing capabilities available which could be used operationally and the outlook is not very good. There is some hope of success in two areas: use of satellite sensing techniques to describe the three dimensional refractivity field and improvement of numerical mesoscale models that are adequate for this purpose. Since entirely rigorous solutions are unlikely to be available soon, empirical data have to be used as well as expert systems and artificial intelligence techniques. In addition, improved direct and remote ground-based refractivity sensing techniques need to be developed. Radiosondes and microwave refractometers will remain the major sources for refractivity profiles. Profiling lidars may supplement techniques under clear sky conditions and their practicability will be further investigated. There is, presently, little hope that radiometric methods can provide profiles with sufficient vertical resolution to be useful for propagation assessment. There is, however, some hope that radars themselves can eventually be used to provide refractivity profiles.

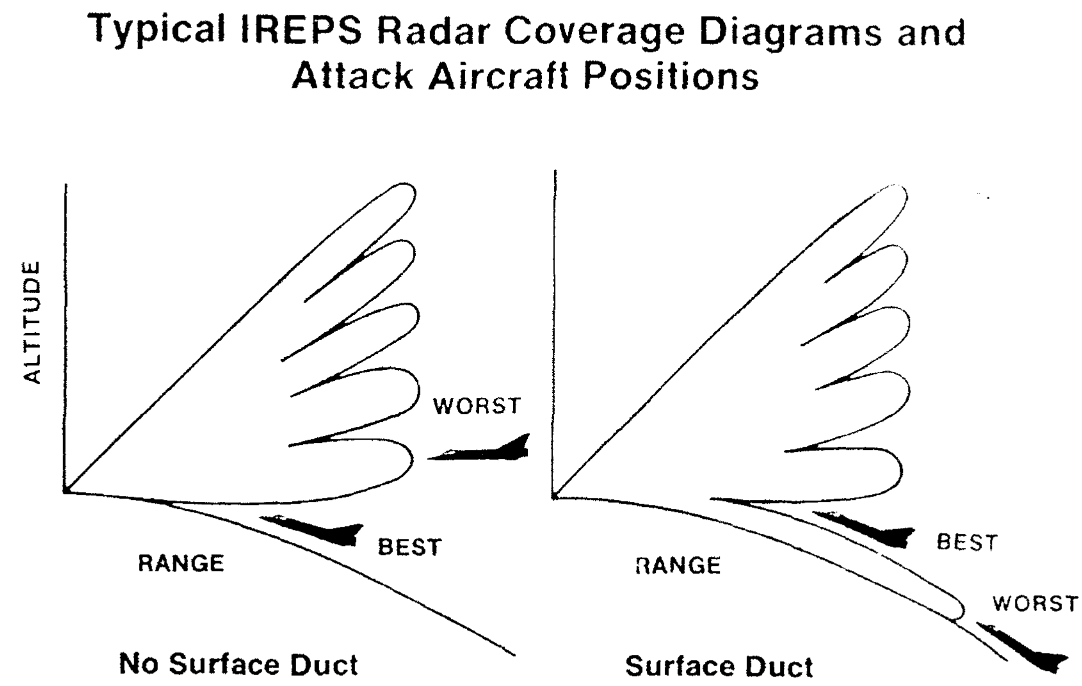

Figure 3. Flight altitudes for attack aircraft for different atmospheric ducting conditions.

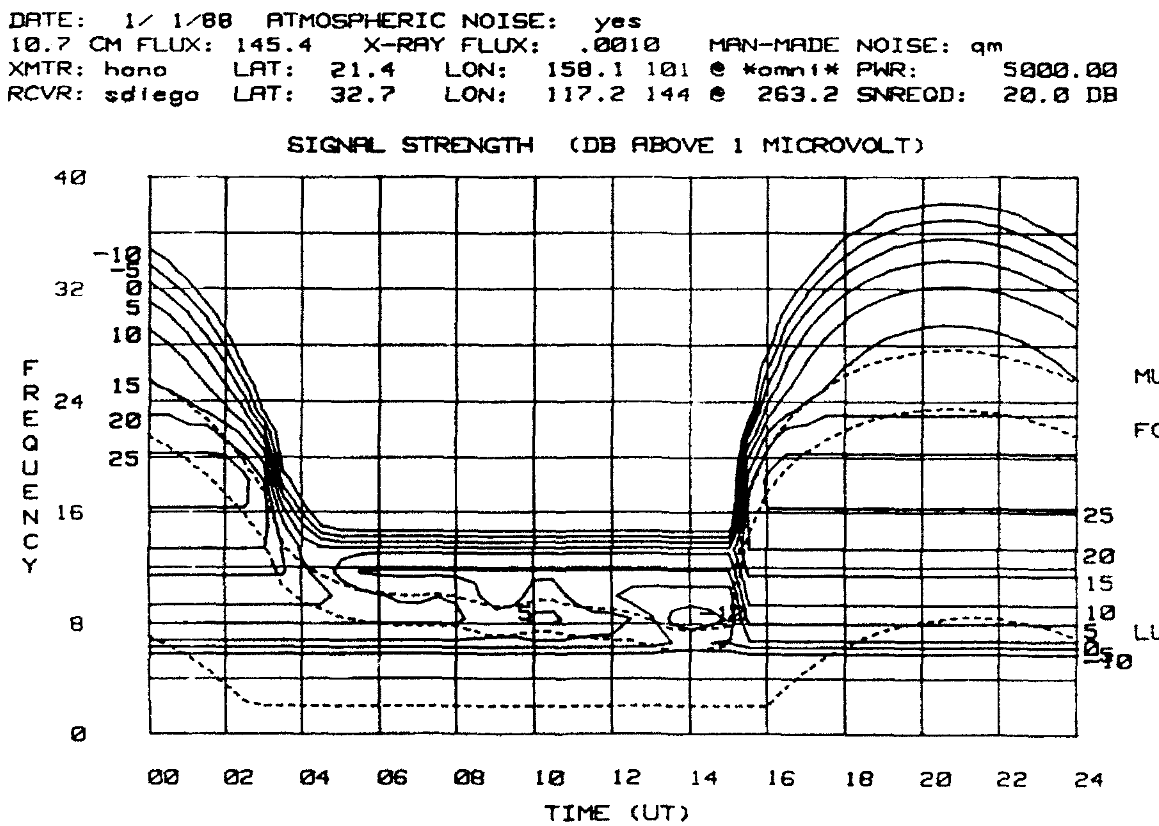

Figure 4. Signal strength contours for high-frequency propagation coverage.

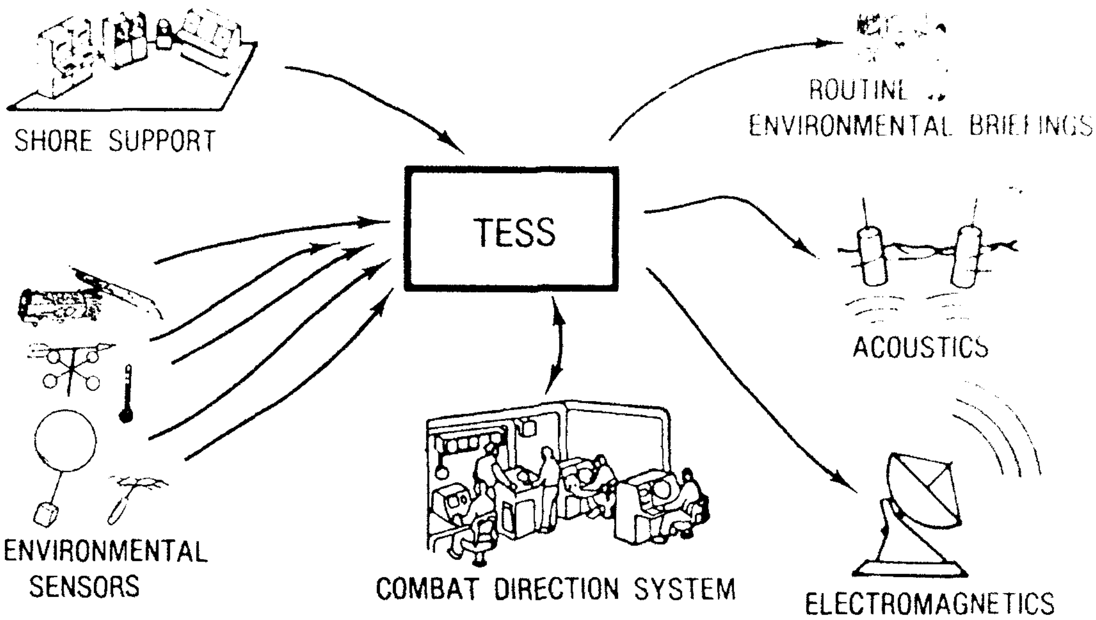

Figure 5. Information flow for the Tactical Environmental Support System (TESS).

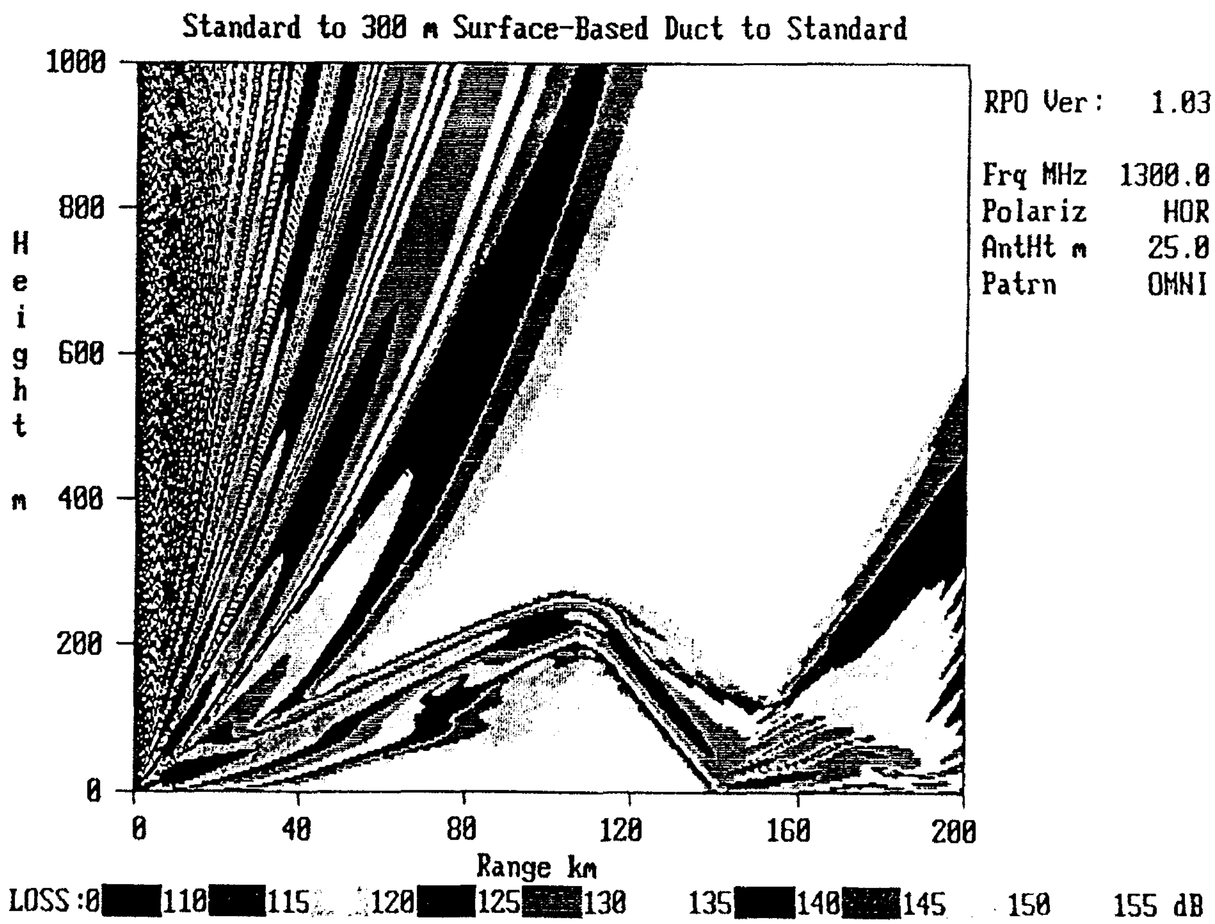

Figure 6. Radar coverage diagram for horizontally varying refractivity conditions.

Long Wave Propagation

So far, propagation in the frequency range below the hf band has not been discussed. It is often referred to as long wave propagation and a number of military applications, especially for strategic use, occupy frequencies in this band. Propagation of long waves over great-circle paths in a homogeneous ionosphere is well understood. Less understood are the effects of propagation over non-great-circle paths, the effects of inhomogeneous ionospheric conditions caused by energetic particle precipitation, sporadic E, electron density ledges and nonreciprocal propagation phenomena. Another area in need of attention is the improvement of atmospheric noise prediction codes. Finally, the often extensive computer time required by longwave propagation codes should be shortened through more efficient algorithms and faster numerical techniques.

High-Frequency Propagation

Empirical data bases are used in short wave propagation modeling and assessment work. These data bases need improvement in both accuracy and spatial/temporal coverage. Profile inversion techniques which are used to derive electron density profile parameters give non-unique answers and need to be refined. Short-term ionospheric fluctuations and tilts are becoming increasingly important for modern geolocation and surveillance systems. An intensive measurement and modeling effort is required to understand and predict such phenomena. Some of the physics of solar-ionospheric interactions and the time scales involved are still poorly understood and require further research. Existing short wave propagation assessment systems are based on simple models. Future systems will need sophisticated models and extensive validation procedures. With increased computer capability, more complex models can be executed fast enough for near-real-time applications. Also, the increasing use and availability of oblique and vertical incidence sounders make this data source an attractive additional input for assessment systems. This would make it possible to update the various ionospheric parameters used in the models which form the basis of these assessment systems. In addition, the availability of computer networks should allow the development of regional, near-real-time models based on a net of sounder measurements.

Transionospheric propagation predictions are limited by the accuracy of total electron content (TEC) values. Much of the difficulty arises from geomagnetic storm effects, traveling ionospheric disturbances, lunar/tidal effects, and other temporal/spatial phenomena. The best and only major improvement over monthly TEC climatology predictions can be obtained by real data observations not more than a few hours old taken where the TEC-time-delay correction is required. Present theories are inadequate to predict these temporal deviations from quiet ionospheric behavior and efforts to improve those deficiencies are recommended.

Climatological models for transionospheric propagation predictions need more and better data for improved spatial resolution. In addition, parameters from the neutral atmosphere and the magnetosphere may provide insight into the reasons for the complexity in the spatial/temporal variability of TEC. For the proper use of more spatially dense data, future ground-based observation networks must have standard format, calibration, editing, processing and interpretation techniques.

Ionospheric scintillations are caused by various plasma instabilities. Approximate stochastic solutions to the propagation problem describe quantitatively the scintillation phenomenon when the statistical properties of the irregularities are known. Morphological models of scintillation have been built to predict the scintillation occurrence and strength as a function of geographical, geophysical and solar parameters. Since ionospheric scintillation can be a limitation to various space-based systems, empirical models have been made available for system design. However, the solar and geomagnetic dependence of scintillation is still not fully understood and requires more attention in the future. Multi-technique measurements have proved very productive and should be the experimental approach for future modeling efforts.

For hf ground-wave propagation assessment, the approximate models now utilized should to be replaced by more complex and comprehensive prediction models. This should improve the accuracy of assessment and would avoid the discontinuity at frequencies where a change in approximation models is now made. New software should allow for a non-standard atmosphere and for sections with different ground electrical properties.

Millimeter-Wave and Electrooptical (EO) Propagation

Figure 7 shows atmospheric attenuation for frequencies above 10 GHz. Molecular absorption and extinction from aerosol particles (haze, fog, clouds, rain, snow etc.) play a major role. The solid curve in the figure denotes molecular absorption which rapidly increases above 10 GHz with alternating peaks and valleys. Of particular interest is the valley just below 100 GHz which offers still acceptably low attenuation rates for many applications. What makes the frequency range between 90—100 GHz attractive is that the relatively small wavelength (approximately 3 mm) permits narrow antenna beams for small apertures. The major advantage of mm-waves over frequencies in the infrared or optical region is that mm-waves are less affected by hazes, fogs, smokes and clouds and are also capable of penetrating foliage. They are also strongly affected by atmospheric refractivity. In the

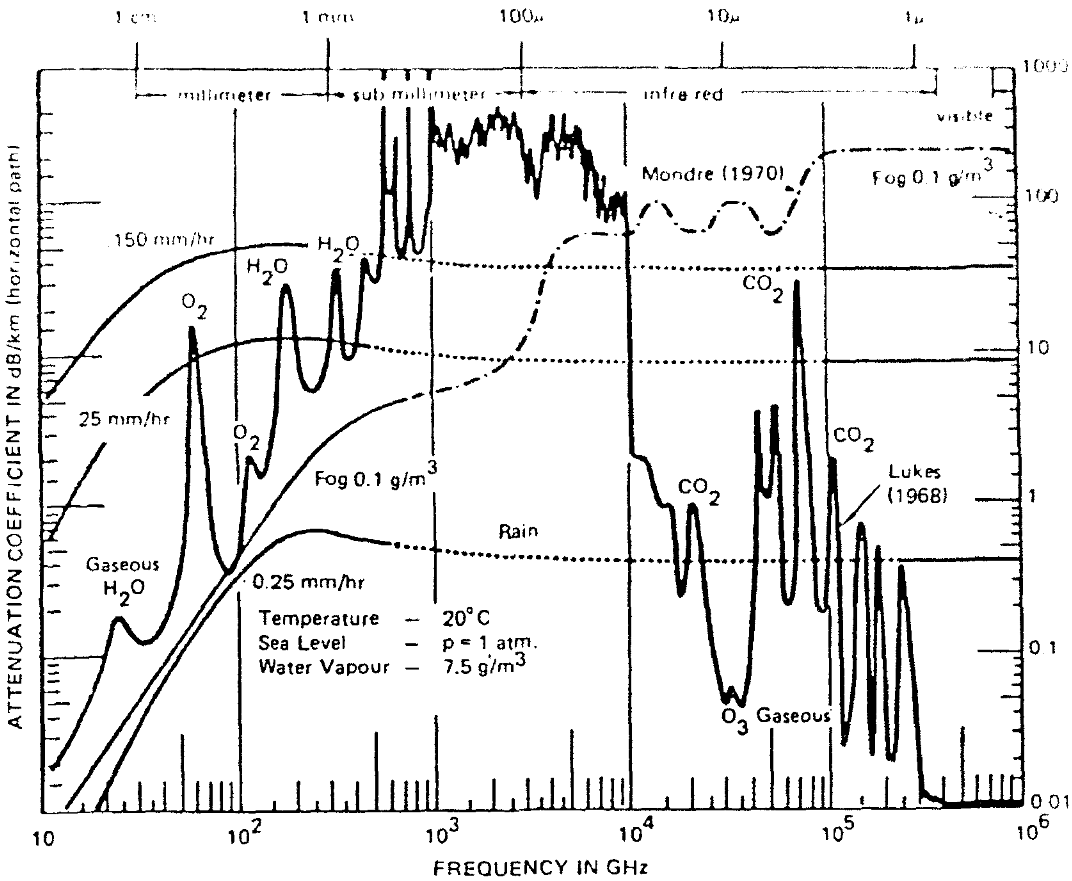

Figure 7. Attenuation coefficients for frequencies above 10 GHz.

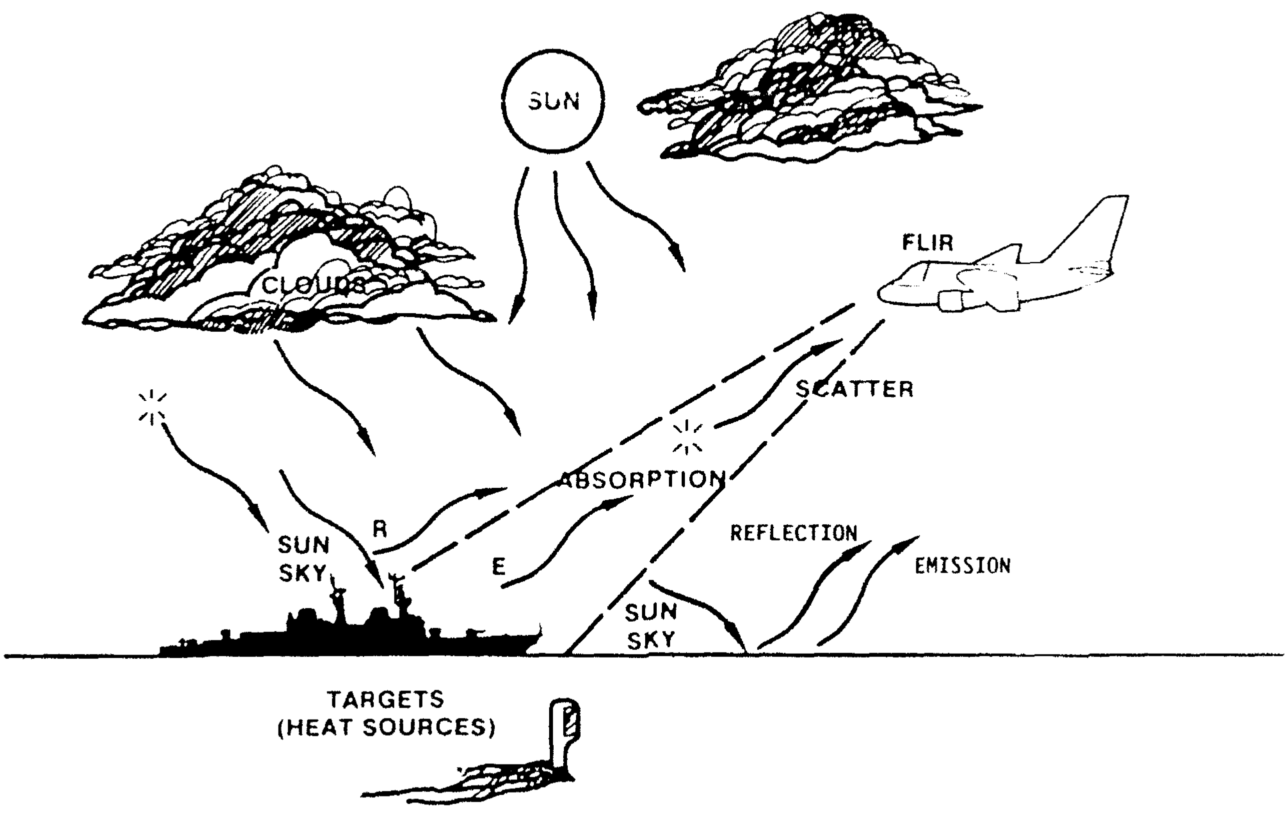

Figure 8. Parameters affecting FLIR (Forward Looking Infrared) performance.

case of near surface ocean propagation the so called evaporation duct dramatically increases signal levels. For example 94 GHz signal levels for a 41 km propagation link in the southern California off shore area are commonly enhanced by 60 dB. Intense mm-wave measurement and analysis efforts are presently being conducted under the sponsorship of the Defense Research Group of NATO.

Molecular absorption decreases for frequencies above 10 THz but is, again, characterized by peaks and valleys. There are several such valleys in the infrared band and molecular absorption is very low for the visible band. EO systems are sensor and weapon systems which rely on electromagnetic radiation in the infrared, visible and ultraviolet wavelength bands. They are of specific importance to military operations because they permit pointing accuracies and covertness not achievable at radio wavelengths. Unfortunately, they are significantly more dependent on the properties of the propagation medium than radio wavelengths. This critical dependency controls their deployment and requires a precise knowledge of the effects of the propagation environment on their performance.

Figure 8 illustrates atmospheric parameters influencing the performance of a Forward Looking Infrared (FLIR) system operating in a marine environment. The primary atmospheric parameters affecting the propagation of radiation in the (EO) bands are: aerosol extinction, molecular absorption, turbulence and refraction. Aerosol extinction is the sum of scattering and absorption by atmospheric aerosols. Shape, chemical composition, and size distribution of atmospheric aerosols are dependent on a number of other, often unknown, parameters (such as air mass origin, relative humidity, wind, etc.) and are difficult to measure and model. Molecular absorption is probably the best understood of the above parameters and, for practical purposes, can be accurately predicted. Atmospheric turbulence is primarily due to temperature fluctuations and may cause beam wander, scintillations and image blurring. Atmospheric refraction may significantly shorten or extend horizon ranges for near-surface geometries which is an important factor in the detection of low-flying anti-ship missiles.

Besides the atmospheric parameters which control propagation, use of some EO sensors requires a knowledge of additional environmental factors. Surveillance systems (such as FLIR and Infrared Search and Track Systems or IRST) sense the temperature difference or contrast temperature between the target and the background. The background temperature is often a complex function of emissivity of the background (atmosphere, sea surface, ice, ground), path radiance and reflections from the sky or other sources. In addition, clutter from sun glint or cloud edges may mask targets or produce false alarms.

Environmental factors affecting EO systems must be known for both the design of such systems and their optimum operational deployment. Design of new EO systems and planning of military operations require good statistical data bases while their actual use necessitates accurate information of the conditions present. Therefore, models need to be developed and validated which relate atmospheric EO parameters to commonly available meteorological data. An example is an aerosol model based on temperature, humidity and wind observations. A particularly challenging task is the development of new sensing techniques for both in-situ and satellite use. Among various approaches are lidars (laser radars), radiometric techniques and a variety of devices which measure angular scattering from aerosols.

Finally, comprehensive technologies have been developed using fibers to transmit EO signals. These technologies are dominated by commercial applications but there are significant military uses that make fiber optics an important concern for EPP. An example is use of ultra-low loss fibers to guide missiles or to remotely control vehicles.

Conclusions

Electromagnetic propagation assessment is crucial in the development of sensor and weapon systems, in military planning and for real-time operations. There are many challenging tasks remaining in all regions of the electromagnetic spectrum. Promising areas for emerging applications are mm-wave and EO wavelength bands. A major concern is the timely and accurate description of the propagation environment. Increasingly sophisticated signal processing techniques will be required for jam resistant, noisy and congested electromagnetic environments. For military operations, electromagnetic propagation assessment must be an integral part of command and control systems.

Dr Juergen H. Richter

Biography

Dr. Richter received the degrees of Diplom-Ingenieur (Electronics Engineering) in 1961 and of Doktor-Ingenieur (Electronics Engineering, subject of dissertation: wave-propagation in inhomogeneous media) in 1963 from the Technische Universitaet, Munich, Germany.

In 1964, he started work in the United States at the Naval Weapons Laboratory, Dahlgren, VA. In 1965, Dr Richter transferred to the Naval Electronics Laboratory, now the Naval Ocean Systems Center in San Diego where he is Head of the Ocean and Atmospheric Sciences Division and directs work in the areas of electromagnetic radio propagation, electro-optics propagation, and underwater acoustics research and development. This involves theoretical and experimental work in geophysics including meteorology and oceanography.

Dr. Richter is Chairman (1991—1993) of Commission F of the U.S. National Committee of the International Union of Radio Science (URSI), U.S. member of NATO Research Group 8 of Panel IV (Atmospheric Effects on EO Systems), the U.S. National coordinator and Deputy Chairman/Chairman (1989—1993) of AGARD's EM Wave Propagation Panel (EPP). From 1983—1986 he served as associate editor for Radio Science. He has been chairman of one AGARD Working Group and co-chaired five AGARD/EPP symposia. He holds two U.S. Patents and has authored over 50 open literature publications.